# Value Stream Mapping and Discrete Event Simulation Applied to Reduce Waste in a Company that Manufactures a Family of Automotive Parts

Tatiany M. da Silva and Joao C.E. Ferreira*

Universidade Federal de Santa Catarina
Departamento de Engenharia Mecânica, GRIMA/GRUCON
Caixa Postal 476, Florianópolis, Santa Catarina, 88040-900, Brazil

***Abstract***

*Lean manufacturing seeks consistent and complete elimination of waste in order to optimize resources. However, the elimination of such waste in most cases is done through of trial and error, which usually entails more costs for the company. Given this scenario, this paper describes the use of Value Stream Mapping (VSM) and Simulation to a family of products in a company that produces machined parts for the automotive sector. This family corresponds to five models of different cylinder heads that undergo similar processing steps and use similar equipment in their processes. In order to identify waste, initially the current state value stream map of the system that manufactures the family of cylinder heads was developed, and thereafter the future state map was built, seeking to reduce or eliminate waste and implement a lean value stream. The future state map was also modeled in a simulation software, in order to evaluate the proposed improvements in the future state and propose scenarios that enable adequate decision making by the managers of the company, such as the event of an increased demand. The use of simulation together with VSM contributed to provide the following additional advantages to using only VSM: (a) use of random data in the analysis of the results, (b) the possibility of modeling different scenarios without changing the physical arrangement of the production line. The results obtained by applying the methods to the cylinder head manufacturing were: reduced lead time, increase in utilization rates, improvement in visual management, and increased productivity. In addition, the production line started to operate with the amount of operators needed to satisfy the demand.*

## 1. Introduction

Due to changing market conditions or the need to meet increasingly distant customers, currently there is a very high fluctuation in demand, which in turn ends up generating more costs such as those caused by overproduction. Usually these changes in demand are not taken into account by the shop floor, i.e. manufacturing is carried out at the same pace. Some problems arising from this scenario are: accumulation of stocks of finished products, low utilization of human resources, and inadequate physical layout. One of the results is the use of labor above than the needed amount.

Any organization must reduce its costs and increase its productivity, and lean manufacturing assists in this process of identifying waste, causing the company to become more competitive. However, in order to achieve a better condition, several adjustments in the production system are necessary [1]. One method that can be used to facilitate the decision making in manufacturing environments without performing any changes in the production process is simulation. Through simulation it can be evaluated if in fact the proposed improvements are adequate to achieve a lean process, without any physical changes. Also, through simulation different scenarios can be considered, providing managers some support to implement best practices [2, 3].

Most works in the literature on the topic of lean manufacturing use Value Stream Mapping (VSM) to propose a future state. However, it is observed that there are few studies that use simulation seeking to propose new scenarios to facilitate the implementation of the future map. Singh et al. [4] conducted a review of researches published since 1990 (in scientific journals, conferences and books) involving VSM and other techniques, and they listed 11 studies (corresponding to 24% of the studies analyzed) using VSM in conjunction with simulation.

This paper makes use of value stream mapping and simulation in order to evaluate and implement a lean value stream in a production line at a company that manufactures a family of engine cylinder heads for the automotive sector.

* Corresponding author: Tel.: +(55) 48 37214021; Fax: +(55) 48 37217615; E-mail: j.c.ferreira@ufsc.br

## 2. LITERATURE REVIEW

### *2.1. VALUE STREAM MAPPING - VSM*

For Rother and Shook [5], the use of VSM provides supply chain managers a new insight into their value stream, allowing the drawing of a new sketch of a better value stream, in order to aggregate the maximum value by eliminating or reducing waste, thus facilitating the implementation of lean manufacturing.

Rother and Shook [5] formalized the VSM tool after they realized the great potential that it offered. The VSM technique is composed of the following steps: (a) initially the current state is drawn from survey data obtained from the factory floor, (b) based on the current state map, the future state is proposed, with the use of lean concepts and techniques, (c) the implementation plan is prepared, which consists of a list of steps and schedule for implementing the future map [5].

### *2.2. SIMULATION*

According to Freitas Filho [6], the improvement of models contributed significantly to the evolution of simulation, which is no longer used only as a last option to support decision making. It is known that, in many real industrial processes, potential changes are first evaluated through simulation before changes are effectively made in the real system, since any change involves costs. For Freitas Filho [6], senior management of various companies have recommended the use of simulation based on the following factors: (a) further details of the simulation model, enabling a simulation analysis of various scenarios, (b) use of animations throughout the simulation, facilitating the visualization of what is being modeled, (c) effective gains in quality and productivity are achieved due to the similarity of behavior between the simulated model and the real system.

However, simulation has some disadvantages, and one instance is the fact that an actual system is often complex, and therefore the simulation results are difficult to understand [3,6]. Therefore, modeling of a real system, such as a production line in the automotive sector, which is the object of study of this paper, consists of a complex system with many peculiarities and requires knowledge of the production process and the use of software. Thus, the interpretation of results requires care not to lead to inaccurate conclusions about the system.

## 3. CASE STUDY: USE OF VSM AND SIMULATION IN A COMPANY THAT MACHINES AUTOMOTIVE ENGINE PARTS

The present study was developed in a world leader in the manufacture of engine blocks and cylinder heads, headquartered in the state of Santa Catarina, Brazil. The company operates in various segments such as iron fittings, steel shots, and profiles. However, the most significant parts in terms of production/sales are those produced for the automotive industry. The study was performed in a production line that manufactures a family of cylinder heads, and this family was chosen for this work because the management of its manufacturing sector was committed to improvements. For instance, its operators already practiced Total Productive Maintenance (TPM). Moreover, the client of this family of engine heads has other families that are also manufactured in the studied company, and the results found in this work could be extended to the other families.

The manufacture of such parts (Figure 1) is characterized by the presence of machining processes such as milling (roughing and finishing) and drilling (to obtain the holes needed for assembling the cylinder head on the block, and for the assembly of other components and as a reference for subsequent processes [7]). The cylinder head is one of the main parts of the engine, and this part needs to be machined so as to provide it a high quality.

The cylinder head is manufactured in batches. Slack et al. [8] mention some examples of batch production processes, particularly the parts manufactured for the automotive industry. The manufacture of the cylinder head occurs in large batches, and since the models that are manufactured on the production line have very similar characteristics, in this case the batch processes resemble serial processes.

Figure 1. Engine cylinder head considered in this research.

## 4. VALUE STREAM MAPPING

### *4.1. CHOICE OF A PART FAMILY*

The first step in the preparation for value stream mapping consists in selecting a product family that will serve as a pilot project. As already mentioned, a family of engine cylinder heads was selected for the pilot project. The production line manufactures five models of cylinder heads that have similar processes and use the same equipment.

### *4.2. CURRENT MANUFACTURING STEPS*

An analysis of the entire value stream was carried out in order to understand it, including the sequence of processes. This was done by walking along the corridors adjacent to the production line, and also talking to the employees in the departments that transform raw materials into finished products of the studied family.

The cylinder heads follow a flow along the production line, in which there are 22 operations that are connected by conveyors, with 11 operators in each shift. The raw material is a cast workpiece, which enters the line and passes through operations that include machining (CNC machining centers), washing, and engraving. The cylinder heads, after being partially packaged in the line, are placed in two types of pallets: (a) wooden pallet, on which 16 parts are sent to foreign markets, or (b) metallic pallet, on which 24 parts are shipped to the domestic market. Then a forklift takes the pallets to the area where they are packed, and then sent to the dispatch area where they wait to be shipped. These processes are included in the current state map, which is described in the nest section.

### *4.3. VALUE STREAM MAPPING – CURRENT STATE*

In order to draw the current state, data were collected from the final dispatch area (with finished parts) to the raw material arrival. Data for the current state map (Figure 2) were obtained by counting parts and timing processes. These acquired data were the basis for the work balance graph of operators in the line considered in this work, and contributed to the mapping of the future state.

In Figure 2 the manufacture of the product is shown in sequence according to each process box icon. For a more detailed mapping of the processes applied to the family cylinder heads, a process box was drawn for each operation. The data box contains the necessary information regarding cycle time (C/T), number of operators, value-added time (VAT), availability of production equipment, and hours worked per day. Material flows from left to right with pushed production, while in some isolated cases we use "FIFO - First In, First Out" conveyors. The flow of information is from right to left, showing the way in which the manufacturing process is planned. At the bottom of the map there is the timeline that is used to compare the production lead time and the processing time (which adds value to the product).

It can be noticed in Figure 2 that for the mapping of the current state it was necessary to adapt some of the symbols provided by the Lean Enterprise Institute (LEI) for VSM, so that the value stream corresponds more closely to the real processes in the company under study. Examples of such adaptations in Figure 2 are the symbols for part rework, parts from different models, and incomplete pallets. In the initial (current) state parts of a specific model were waiting for the line to process another model, and consequently a significant amount of space was occupied in the layout of the line until the same part model entered again the line.

It can be noticed in the current state map that the setup time (ST) was not considered, since in the line under study the processes until operation 45 are the same for any of the five models. From operation 50 onwards processes change according to the model. Since the machining centers have probes that identify within seconds the model that will be machined , the setup time is disregarded.

Based on the drawing of the current state, an analysis of the value stream was performed considering the wastes of lean manufacturing, which the ones that were identified are listed below:

- Overproduction/inventory: the amount of overproduced finished parts in the dispatch area totaled 9.71 days, which is higher than the maximum inventory stipulated by the Production Planning and Control (PPC), becoming one of those responsible for the increased lead time of the line.
- Waiting: the following were identified as contributing to waiting: operator waiting for the machine to finish its cycle, operator waiting for parts or materials, parts awaiting the end of processing a different model. In the work balance graph of the current state it was noticed a low occupancy of the operators. According to Rother and Harris [9], when the operator waits for the machine it is a waste of his/her intellect, since the operator is not involved in other activities.
- Excessive transport of materials: raw parts were transported without real need. Often the forklift driver, when faced with the line full of parts, had to leave the new raw parts outside the demarcated area, creating more unnecessary transport.

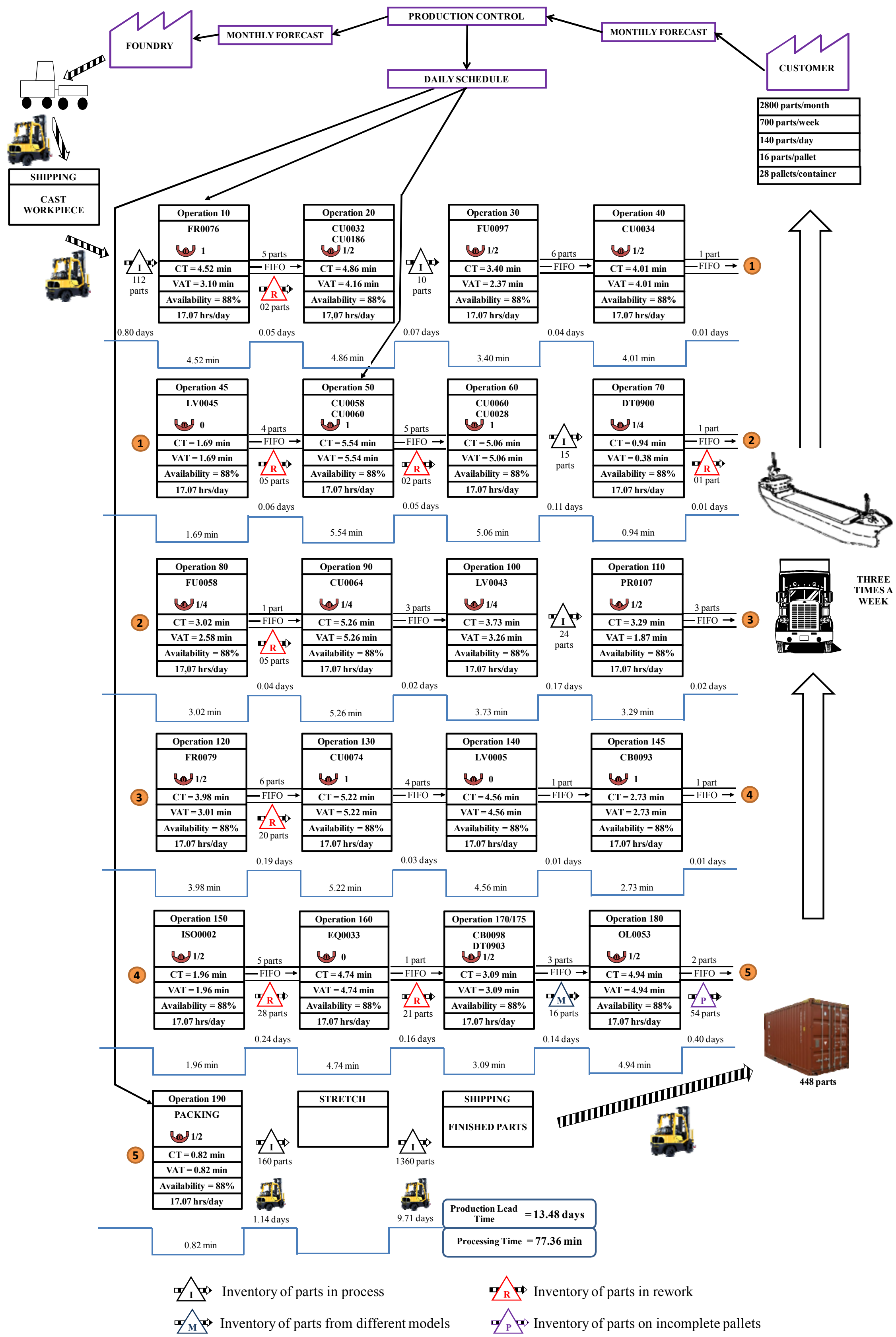



Figure 2. Value Stream Map – Current State.

• Unnecessary movement of operators: the family of products studied operated in three shifts, with the first two shifts working with full line (a total of 11 operators), whereas the third shift had 3 operators in bottleneck operations. This lead to work that did not add value and unnecessary operator movements, because operators the next day had to send the parts to be processed. Another factor that increases the movement is the need to move parts to a coordinate measuring machine (CMM) after nearly all operations. Furthermore, the layout of the line contributes to the increase of movement since many operations are very distant from each other.
• Defects: there was the occurrence of parts with defects throughout the line, generating more costs related to materials or operator activity for parts rework. This generates additional processing, such as the need to inspect more parts or remove parts from the line, increasing the time of no added value.

### *4.4. Value Stream Mapping – Future State*

For the proposals suggested in the future map, it was thought initially to make the cycle times of the machines closest to the takt time, in which case the pace of work required to meet the customer would be 6.44 min/part for each of the two shifts. However, this modification would imply a major change in the layout and the processes, especially in dedicated machines such as the milling and the engraving machines, which have very low cycle times.

Another situation that would interfere in having the time equal to the takt time cycle would be the possible demand variations, because in the period studied the line was working with low capacity and with only two shifts. Therefore, in order to meet possible demand changes, it was considered to adjust the amount of operators according to the demand.

It was noticed that even with decreasing demand, the number of operators remained the same, leading to a low throughput identified in the work balance graph of the current state, besides the wastes of overproduction and waiting that were caused.

Therefore, in view of the work balance graph of the current state, we tried to include in the future map (Figure 3) changes seeking to better utilize manpower, identified on the map by the following symbols of kaizen operations: 20, 30, 40, 50, 60, 70, 80 90, 100, 110, 120, 130, 145, 150, 170, 175, 180, and 190, as well as improvements related to the packaging processes. Thus, it is proposed improvements in devices, eliminating extra processing, reducing waiting times, combination of activities, improvements in visual and material management by means of kanban, and changes in packaging through two scenarios: (a) optimization of the already existing pallet with parts into a new configuration, and (b) use of returnable packaging through the reverse logistics concept.

Also, according to the future map, we tried to develop continuous flow wherever possible, without overlapping boxes of processes. We used only FIFO, and in situations where interruptions occurred in the stream, supermarkets are proposed for supplies of parts coming from the casting supplier. Also, we chose to produce for a supermarket of finished products.

## 5. Simulation

### *5.1. Simulation of the Current State*

The amount of proposed changes to the layout of the line in the future state map is significant, and this motivated the use of simulation to evaluate these changes. Simulation was initially carried out for the current state map, in order to build and validate the simulation model compared to the real system. Through simulation, the same processing time of 77.4 minutes was obtained for the current state map. For the simulation it was initially used the constant data displayed on the map. Subsequently, we performed the simulation with stochastic data represented by a normal distribution, which was obtained by the analysis of the collected times, using the Input Analyzer module of the Arena software, and the results were obtained with 10 replications.

### *5.2. Simulation of New Scenarios*

Based on the current state map a preliminary study was performed of the activities that do not add value, such as OP 100 (washing machine): if this operation could be eliminated or replaced by OP 45 (a washing machine that is more efficient than the one of OP 100), or if it was even possible to combine activities with the gain of one operator.

Regarding the possibility of combining the activities, this new scenario was simulated with a setting of 8 operators for a demand of 150 parts, and another setting for a maximum demand of 162 parts, both for two shifts. For the first situation daily production increased to 150 cylinder heads without compromising the efficiency of the line, which is approximately 88% (Figure 4a). However, if production is performed at full capacity for two shifts, i.e. 162 cylinder heads per day, this new configuration would compromise the efficiency of the line and possibly another production shift (Figure 4b) would be necessary.

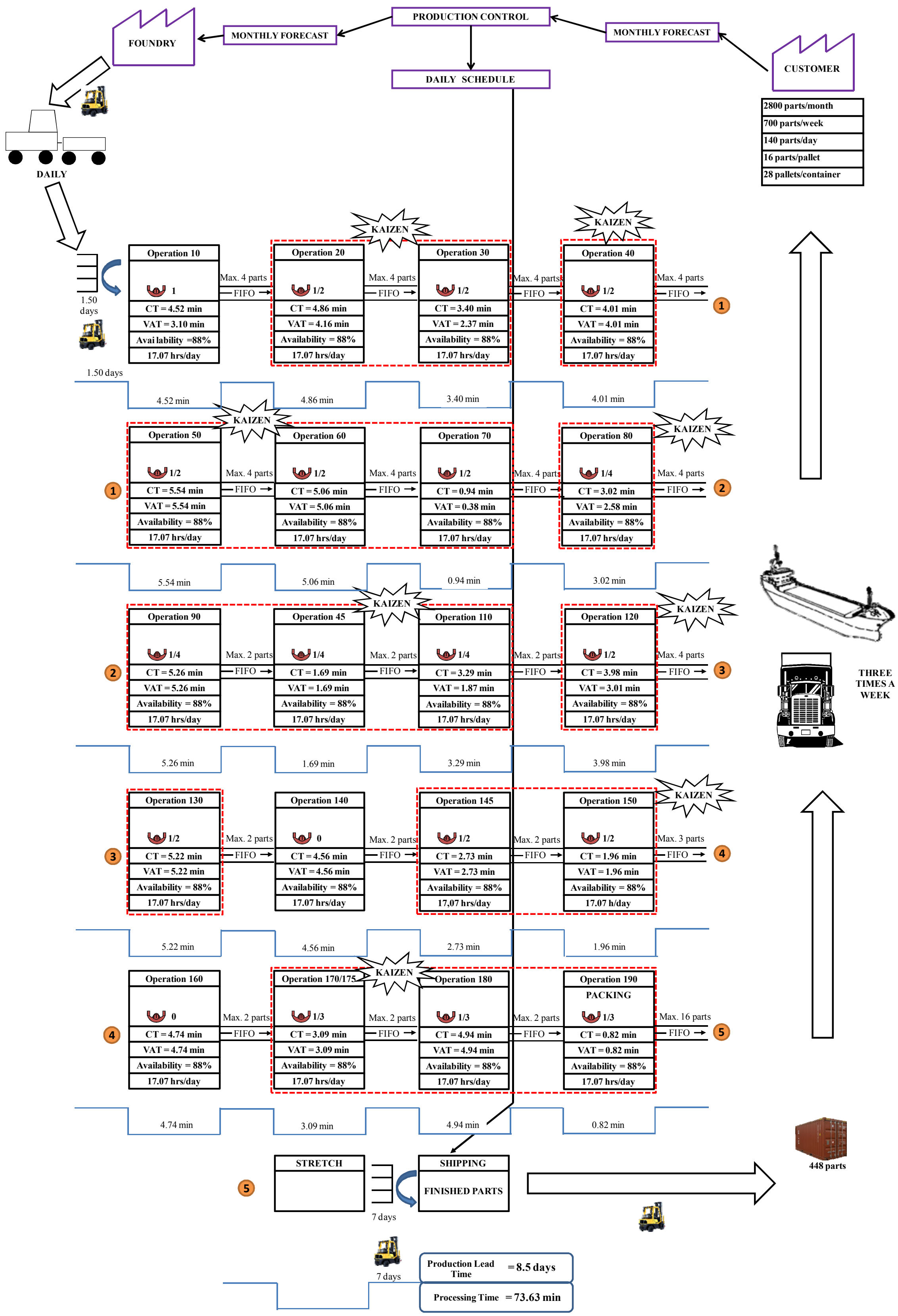
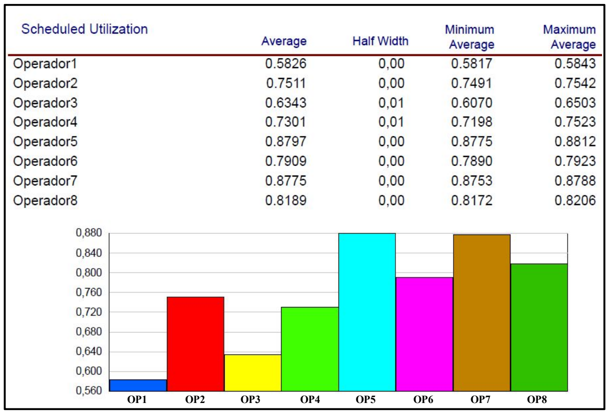


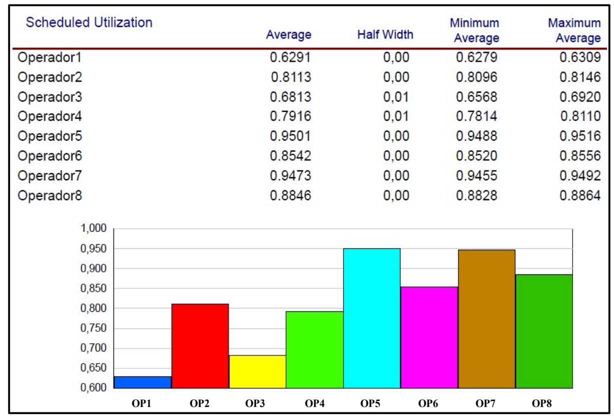

Figure 3. Value Stream Map – Future State.



| Scheduled Utilization | Average | Half Width | Minimum Average | Maximum Average |
|---|---|---|---|---|
| Operador1 | 0.5826 | 0,00 | 0.5817 | 0.5843 |
| Operador2 | 0.7511 | 0,00 | 0.7491 | 0.7542 |
| Operador3 | 0.6343 | 0,01 | 0.6070 | 0.6503 |
| Operador4 | 0.7301 | 0,01 | 0.7198 | 0.7523 |
| Operador5 | 0.8797 | 0,00 | 0.8775 | 0.8812 |
| Operador6 | 0.7909 | 0,00 | 0.7890 | 0.7923 |
| Operador7 | 0.8775 | 0,00 | 0.8753 | 0.8788 |
| Operador8 | 0.8189 | 0,00 | 0.8172 | 0.8206 |



(a) demand=150 heads/day



| Scheduled Utilization | Average | Half Width | Minimum Average | Maximum Average |
|---|---|---|---|---|
| Operador1 | 0.6291 | 0,00 | 0.6279 | 0.6309 |
| Operador2 | 0.8113 | 0,00 | 0.8096 | 0.8146 |
| Operador3 | 0.6813 | 0,01 | 0.6568 | 0.6920 |
| Operador4 | 0.7916 | 0,01 | 0.7814 | 0.8110 |
| Operador5 | 0.9501 | 0,00 | 0.9488 | 0.9516 |
| Operador6 | 0.8542 | 0,00 | 0.8520 | 0.8556 |
| Operador7 | 0.9473 | 0,00 | 0.9455 | 0.9492 |
| Operador8 | 0.8846 | 0,00 | 0.8828 | 0.8864 |



(b) demand=162 heads/day

Figure 4. Results of the simulation for different demands (2 shifts and 8 operators).

### *5.3. Choosing the Best Scenarios*

Through simulation we identified the possibility of not meeting the demand with 8 operators and thus the new scenario chosen was increased to 9 operators per shift with maximum production capacity of 162 cylinder heads per day. Compared with the current situation, the chosen scenario leads to an increase in the occupancy rate of the operators, but even so such occupancy rate is within the standards set by the company. It was noted that in some operations the occupancy rate was still around 60% due to layout constraints that prevent a better use of the operators. In this case, these operators would be available to help others.

Thus, the activities of OPs 20, 30, 40, 50, 60, 145, 150, 170, 175, 180, and 190 would be redistributed, resulting in the following scenario: OPs 20 and 30 - one operator, OPs 40 and 50 - one operator, OPs 50 and 60 - one operator, Ops 145 and 150 - one operator, OPs 170 and 190 - one operator. The other operations would not be altered.

Based on the proposed improvements in the future map and after evaluation by simulation, the proposed changes were actually implemented in the production line for cylinder heads. It is shown in Table 1 a summary of the current state compared with the deployed future state, with a significant improvement in lead time, which previously was equal to 13.48 days, becoming equal to 8.17 days. There was also an increase in the average occupancy rate of the line (from 55% to 65%), and a 31% increase in throughput.

Table 1. Comparison between the values of the initial (current) state, future state, and those obtained after the implementation.

| | Current State | Future State | Implementation in the production line |
|---|---|---|---|
| Demand | 140 parts/day | - | 150 parts/day |
| Number of operators | 11 | 8 | 9 |
| Lead Time | 13.5 days | 8.5 days | 8.2 days |
| % Occupancy | 55% | - | 65% |
| Throughput | - | - | ↑ 31% |

## 6. Conclusion

In this work the methods of Value Stream Mapping (VSM) and simulation were used to support the implementation of a lean value stream in a family of engine cylinder heads in a company that manufactures automotive parts. Simulation was very important to validate the changes proposed by VSM as well as to eliminate scenarios that would not be efficient.The proposed improvements were implemented, resulting in significant gains that had already been anticipated by simulation. With regard to waste, the following improvements were achieved: reduction in waiting at the end of a machine cycle through better distribution and utilization of manpower (multifunctional operators); decrease in the amount of reworked parts, reducing unnecessary movement; reduction of in-process inventory. In addition, the production line started to operate with the amount of operators needed to satisfy the demand.

Despite the improvements achieved with the implementation of lean, there was the difficulty of obtaining the engagement of people early in the project, because since there is the presence of several areas of the company, not always people become more aware of the need for change. Also, it was hard to keep the commitment of the team along the development of this work. Training sessions were held with the operators so that they apply the lean philosophy in their daily activities.

This work can be used as a basis for other projects in the company, such as the possibility of using a returnable standard packaging to increase dispatching speed. In addition, we created a continuous improvement team and multifunctional operators who became multipliers.

For future research simulation could be used to verify both the number of required operators and the best arrangement for the production lines that are being developed at the company, achieving a better utilization of resources (including operators), and reducing the distances between the operations.

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